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SUMMARY: As part of a longitudinal study of the respiratory health effects of indoor and outdoor air pollutants, pulmonary function, respiratory illness history, and symptom history were recorded at 2 successive annual examinations of 10,106 white children living in 6 cities in the United States. Parental education, illness history, and smoking habits also were recorded, along with the fuel used for cooking in the child's home. Maternal cigarette smoking was associated with increases of 20 to 35% in the rates of 8 respiratory illnesses and symptoms investigated, and paternal smoking was associated with smaller but still substantial increases. Illness and symptom rates were linearly related to the number of cigarettes smoked by the child's mother. Illness rates were higher for children of current smokers than for children of ex-smokers. The associations between maternal smoking status and childhood respiratory illness and symptoms were reduced but not eliminated by adjustment for parental illness history. Levels of forced expiratory volume in one second (FEV_1) were significantly lower for children of current smokers than for children of nonsmokers at both examinations and highest for children of ex-smokers. Levels of forced vital capacity (FVC) were lower for children of nonsmokers than for children of current smokers at both examinations, but the difference was statistically significant only at the first examination. Both the increase in mean FVC and the decrease in mean FEV_1 among children of current smokers were linearly related to daily cigarette consumption. None of the respiratory illnesses and symptoms studied was significantly associated with exposure to gas cooking in the child's home. The largest odds ratio for respiratory illness before 2 yr of age was 1.13 ($p = 0.07$). Exposure to gas stoves was associated with reductions of 0.7% in mean FEV_1 and 0.6% in mean FVC at the first examination ($p < 0.01$) and reductions in both measures of 0.3% at the second examinations (NS). The estimated effect of exposure to gas stoves was reduced by approximately 30% after adjustment for parental education. These results provide strong support for a causal effect of sidestream cigarette smoke on increased respiratory illness and reduced FEV_1 values in preadolescent children. They also suggest that exposure to gas stoves may be associated with reduced pulmonary function but do not show increases in respiratory illness among children exposed to gas stoves. Understanding of the health effects of these indoor pollutants will be improved by studies quantifying individual exposure to cigarette smoke and gas stove combustion products.

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Passive Smoking, Gas Cooking, and Respiratory Health of Children Living in Six Cities[1-3]

J. H. WARE, D. W. DOCKERY, A. SPIRO, III, F. E. SPEIZER, and B. G. FERRIS, JR.

SUMMARY As part of a longitudinal study of the respiratory health effects of indoor and outdoor air pollutants, pulmonary function, respiratory illness history, and symptom history were recorded at 2 successive annual examinations of 10,106 white children living in 6 cities in the United States. Parental education, illness history, and smoking habits also were recorded, along with the fuel used for cooking in the child's home. Maternal cigarette smoking was associated with increases of 20 to 35% in the rates of 6 respiratory illness [illegible] investigated, and paternal smoking was associated with smaller but still substantial increases. Illness and symptom rates were linearly related to the number of cigarettes smoked by the child's mother. Illness rates were higher for children of current smokers than for children of ex-smokers. The associations between maternal smoking status and childhood respiratory illnesses and symptoms were reduced but not eliminated by adjustment for parental illness history. Levels of forced [illegible] and second (FEV$_1$) were significantly lower for children of current smokers than for children of nonsmokers at both examinations and highest for children of ex-smokers. Levels of forced vital capacity (FVC) were lower for children of nonsmokers than for children of current smokers at both examinations, but the difference was statistically significant only at the first examination. Both the increase in mean FVC and the decrease in mean FEV$_1$ among children of current smokers [illegible] daily cigarette consumption. None of the respiratory [illegible] studied was significantly associated with exposure to gas cooking in the child's home. The largest odds ratio for respiratory illness before 2 yr of age was 1.13 ($p = 0.07$). Exposure to gas stoves was associated with reductions of 0.7% in mean FEV$_1$ and 0.8% in mean FVC at the first examination ($p < 0.01$) and reductions in both measures of 0.3% at the second examinations (NS). The estimated effect of exposure to gas stoves was reduced by approximately 30% after adjustment for parental education. These results provide [illegible] evidence of adverse effects of sidestream cigarette smoke on increased respiratory illness and reduced FEV$_1$ values in preadolescent children. They also suggest that exposure to gas stoves may be associated with reduced pulmonary function but do not show increases in respiratory illness among children exposed to gas stoves. Understanding of the health effects of these indoor pollutants will be improved by studies quantifying individual exposure to cigarette smoke and gas stove combustion products.

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Introduction

Acute illness resulting from exposure to high concentrations of indoor air pollutants is a well-recognized clinical entity. Tragic episodes arising from suicide attempts or accidents with carbon monoxide are too common to require detailed documentation. Far more difficult to assess are the health effects of indoor exposures to the concentrations of gases and particles encountered in the usual activities of daily living.

Because most people spend more than 80% of their time indoors (1,2), and because efforts to reduce air exchanges in homes have increased in the last several years, it is important to determine whether air contaminants from indoor sources affect respiratory illness rates and pulmonary function levels in children and adults. Respirable particulate concentrations are higher in homes of smokers than in homes of nonsmokers (3, 4), and increased concentrations of nitrogen dioxide (NO_2) are found in homes where gas is used for cooking (5-9). However, the respiratory health effects of exposure to sidestream cigarette smoke and gas combustion products have only recently been investigated.

Most studies of children exposed to cigarette smoke have found increases in respiratory illnesses and symptoms (10-16) and reductions in indexes of pulmonary function (11-17), although a few studies have failed to find one or both of these associations (10, 18, 19). Several studies have found increased respiratory illness and symptom prevalence in homes with gas stoves (10, 20-22), but the associations have often been weak, and other studies have found no significant associations (23-25). Most studies of gas cooking and pulmonary function levels have found no association (10, 22, 23), although Hasselblad and associates (26) reported reduced FEV$_1$ among older girls living in homes with gas stoves. Thus, the literature indicates reasonably good agreement about the health significance of passive smoking but is inconsistent regarding the effects of gas stoves.

The Six-Cities Study of the Health Effects of Respirable Particulates and Sulfur Dioxide (27) is a longitudinal study of the respiratory health effects of air pollutants among children and adults living in 6 cities in the United States. Although the study is longitudinal, completion of the first 2 annual visits by participating children permits a cross-sectional analysis of the effects of stove type and parental smoking habits on pulmonary function, respiratory illnesses, and symptoms at enrollment and the first follow-up visit. These results update previous reports on gas stove exposure and passive smoking from this study (28, 29). The previous reports presented preliminary analyses from data provided by 8,120 white children from 6 to 10 yr of age and indicated increased respiratory illness before 2 yr of age and decreased pulmonary function levels in children

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[1] From the Departments of Biostatistics and Environmental Science and Physiology, Harvard School of Public Health, the Channing Laboratory, Department of Medicine, Harvard Medical School, and Brigham and Women's Hospital, Boston, Massachusetts.

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[3] Requests for reprints should be addressed to Dr. B. G. Ferris, Jr., Department of Environmental Science and Physiology, Harvard School of Public Health, 667 Huntington Avenue, Boston, MA 02115.

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exposed to gas stoves. Parental smoking was found to be associated with increased respiratory illness but not with pulmonary function levels. This report presents a reassessment of those associations in the complete study cohort of 10,106 white children, using recently reported normal values in the pulmonary function analyses (30). We provide evidence for an exposure-response relationship between the amount of maternal cigarette smoking and indexes of respiratory health. We also examine the importance of parental respiratory illness and socioeconomic status as predictors of illness in children.

Methods

Study Population

The six cities were selected to represent a range of air quality based on their historic levels of outdoor pollution. Cooperation of local school authorities was required, and the school districts selected had to be of manageable size. The 6 communities included Watertown, Massachusetts; Kingston and Harriman, Tennessee; a geographically defined area in the southeast section of St. Louis, Missouri; Steubenville and Mingo Junction, Ohio; Portage, Wisconsin and surrounding towns; and a random sample of 50% of the schools in Topeka, Kansas.

In each city, the initial examinations included all first- and second-grade school children in both the public and private schools within the community. Because Portage was considerably smaller than the other districts, the initial examination included children up to the fifth grade. In each year after the initial examination, the same children were seen again and a new first grade was added until approximately 1,500 children were enrolled in each community. All available children in each community are reexamined annually. The population for this analysis is made up of all white children enrolled during the first 3 visits to each city. Nonwhite children were excluded from this analysis because the other racial and ethnic groups were relatively small.

Health, Exposure, and Demographic Information

At each visit, a questionnaire was sent home (with an explanatory letter) to be completed by a parent or guardian and returned to the school. Families reported the number of persons living in the home and their smoking habits, parental occupation and educational background, and the fuels used for cooking and heating. Information regarding respiratory illnesses and symptoms was requested in a format similar to that recommended by the Epidemiology Standardization Project (31). Although children in the fourth and higher grades were asked separately about their smoking habits, smoking was rare in the young children included in this analysis, and was not considered as a possible risk factor.

The children were examined at school. Their weight and standing height in stocking feet were measured, and they performed forced expiratory maneuvers on a recording spirometer (Stead-Wells survey spirometer; Warren E. Collins, Braintree, MA) while sitting with free mobility and without a noseclip. Each child performed at least 5 forced expirations but not more than 8. Forced vital capacity (FVC) and forced expiratory volume in one second (FEV_1) were measured from the acceptable blows determined by the tester. The mean of the best 3 efforts was calculated, corrected to body temperature and water saturation. Detailed description of measurement procedures is given elsewhere (30).

Of the respiratory illnesses and symptoms surveyed at the initial visit, responses concerning history of bronchitis, doctor-diagnosed respiratory illness before 2 yr of age, and respiratory illness in the previous year that kept the child at home 3 days or more were analyzed. From the questionnaire given at the first follow-up visit 1 yr later, the frequency of respiratory illness in the previous year that kept the child at home 3 days or more, bronchitis in the previous year, and the prevalence of persistent cough (for 3 months of the year or more) and persistent wheeze (most days or nights or apart from colds) were analyzed. An index of lower respiratory illness, indicating the presence of either bronchitis, respiratory illness, or persistent cough during the past year, was also computed and analyzed.

Pulmonary function values were transformed to their logarithms (*see* Statistical Methods) and then expressed as residuals (differences) from height, weight, age, and sex-specific expected values based on previously reported prediction equations (30). Pulmonary function residuals from the initial and first follow-up visits were investigated for associations with exposure to gas stoves and sidestream cigarette smoke. Results of these analyses are reported as deviations from 100% of the ratio of observed to expected pulmonary function level.

Parental smoking status was expressed both as a three-level variable based on reported smoking history (never smoked, ex-smoker, and current smoker) and as an ordinal variable, coded as the reported number of cigarettes currently smoked per day by each parent. To determine a dichotomous variable for cooking fuel, homes using any gas for cooking were classified as gas homes. A positive history of parental respiratory illness was defined as a history of bronchitis, emphysema, or asthma for either parent. To adjust for the effect of socioeconomic factors on respiratory health, we defined 3 classes based on the mean number of years of schooling of the parents (< 9, 9–12, > 12). For children in single-parent households, the years of education of that parent were used. As an alternative measure of socioeconomic status, we considered an index proposed by Green (32) based on education and occupation.

Statistical Methods

The illness and symptom outcomes were analyzed by multiple logistic regression (33, 34), using BMDP (35). For each outcome, a regression model was constructed, including gas cooking and parental smoking variables (because of their a priori interest as risk factors), and other confounding variables as identified by prior analyses. Statistical significance of regression coefficients was determined by the chi-square approximation for the likelihood ratio statistic. Independent variables considered included maternal and paternal smoking status, stove type, heating fuel, air conditioning, and parental education. Because heating fuel and air conditioning did not enter significantly into any regression model, these variables are not discussed further. City-cohort, an 18-category variable designating the city and year of enrollment, was included in every model to eliminate possible confounding effects caused by city of residence and entry cohort. Parental respiratory illness history was then added to the explanatory model to assess its importance as an intermediate or explanatory variable. The logistic regression analysis gave a regression coefficient and standard error for each exposure variable. These coefficients were reexpressed as point estimates and 95% confidence intervals for the relative odds of disease for exposed relative to unexposed children. The adequacy of these summaries was examined by graphic and tabular inspection of the illness and symptom rates for groups of children defined by values of the independent variables. Directly standardized rates, based on the entire sample as the reference population, were used to summarize illness and symptom rates in different exposure groups. To avoid empty cells, the rates given in table 4 are standardized for city rather than city-cohort.

We have previously reported (30) that for preadolescent children, FVC and FEV_1 should be expressed on the logarithmic scale to quantify variability as a percentage of the expected pulmonary function level. That report gave expected values for the logarithm of FEV_1, $ln(FEV_1)$, and of $ln(FVC)$, based on a linear regression of observed values on sex and the logarithms of height, weight, and age. For this analysis, residuals were defined for each child by the difference between the logarithms of the observed and expected values of FEV_1 and FVC (or equivalently, the logarithm of the ratio of observed to expected). These residuals were investigated further by multiple regression analysis. For each visit and each pulmonary function outcome, an explana-

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TABLE 1

NUMBER OF WHITE CHILDREN SEEN BY CITY AND SCHOOL YEAR AT THE INITIAL EXAMINATION, AND TOTAL NUMBER OF WHITE CHILDREN REEXAMINED APPROXIMATELY ONE YEAR LATER

City	Season	First Examination						Second Examination (total)
		74–75	75–76	76–77	77–78	78–79	Total	
Watertown	Fall	613	384	387			1,384	1,197
Kingston	Spring	533	345	378			1,256	1,030
St. Louis	Fall		1,171	749	197		2,117	1,856
Steubenville	Spring		824	475	479		1,778	1,559
Portage	Fall			701	856	320	1,677	1,493
Topeka	Spring			1,412	275	207	1,894	1,449
Total							10,106	8,384

tory model was constructed by an approach parallel to that described previously for analysis of respiratory illnesses and symptoms. To express the results as percentage change, we computed the antilogarithm of each regression coefficient, and multiplied by 100. Thus, associations between outcomes and indirect exposure measures are expressed as change from 100% in the ratio of observed to expected FEV, or FVC associated with a change in exposure status, along with 95% confidence intervals or approximate standard errors derived from the analysis on the logarithmic scale. Results are given from the first 2 annual spirometric examinations of participating children.

Results

Sample

During the first 3 visits to the 6 cities, 11,048 white children entered the study. Analyses for this report were restricted to the 10,106 children 6 to 9 yr of age at enrollment (table 1). At the first follow-up visit, 8,380 (83%) of these children were reexamined. Reexamination rates varied from a low of 77% in Topeka, where follow-up was affected by school closings, to a high of 89% in Portage. Sample sizes for individual symptom, illness, and pulmonary function analyses varied because of missing data, particularly for respiratory illness before 2 yr of age, which was not included in the questionnaire used during the first visit to Watertown and Kingston Harriman.

Of the 10,106 children, 1,107 (11.0%) did not have acceptable spirometric data. The frequency of unacceptable spirometic tests was strongly related to age of the child. The rate for those 6 yr of age was 15.2%; for those 7 yr of age 9.6%; for those 8 yr of age, 7.4%; for those 9 yr of age, only 5.6%. At the first follow-up visit, the overall frequency of unacceptable tracings dropped to 5.7%. There was no association of unacceptable lung function examinations with any reported respiratory illness or symptom after controlling for age and examination.

Demographic Variables, Family History, and Respiratory Health

Boys had uniformly higher illness and symptom rates than did girls (table 2). All respiratory illnesses and symptoms, except history of bronchitis, were reported more frequently for younger than for older children. The negative association between illness before the age of 2 and age suggests that parents

TABLE 2

FREQUENCY (RATE PER 1,000) OF REPORTED ILLNESSES AND SYMPTOMS, BY SEX, AGE, CITY, PARENTAL EDUCATION, AND REPORTED PARENTAL RESPIRATORY ILLNESS HISTORY, DIRECTLY STANDARDIZED FOR SEX, AGE, AND CITY

	1st Examination			2nd Examination				
	Doctor-Diagnosed Illness before age 2	History of Bronchitis	Respiratory Illness Last Year	Respiratory Illness Last Year	Bronchitis	Cough	Wheeze	Lower Respiratory Index
Number	9,004	10,008	9,994	8,292	8,288	8,264	8,237	8,240
Sex								
Boys	241	163	140	148	89	95	127	237
Girls	191	138	134	137	80	84	102	219
Age*								
6	227	155	144	–	–	–	–	–
7	212	148	140	148	92	99	121	239
8	222	151	124	144	78	88	113	228
9	183	153	108	129	81	87	120	213
10	–	–	–	121	77	87	92	194
City								
Portage	223	141	89	87	45	71	111	147
Topeka	208	134	125	155	82	74	115	224
Watertown	129	113	139	156	56	62	89	216
Kingston	341	195	181	218	128	105	148	313
St. Louis	198	127	126	94	80	106	111	204
Steubenville	221	210	171	168	117	119	125	281
Parent's Education								
<High school	265	145	152	133	87	115	146	236
High school	220	150	137	141	82	90	118	225
>High school	195	157	130	145	86	82	94	228
Parent's Illness								
No	174	116	109	112	62	75	91	184
Yes	299	261	207	197	158	138	184	330

* Excludes forty-four 7-yr-old and nine 11-yr-old children at the second examination.

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are less likely to recall early illnesses as the child matures. Rates varied substantially among cities, typically being highest in Kingston and Steubenville. Rates also varied within city from year to year (not shown). Thus, further analyses were adjusted for sex, age, and city-cohort. Illness before 2 yr of age, cough, wheeze, and respiratory illness at the initial examination were negatively associated with level of parental education (table 2). For the other 4 outcomes, the association was either absent or weakly positive. The effect on risk factor analyses of controlling for education or other measures of socioeconomic status is discussed below.

The strongest risk factor for respiratory illness among these children was a history of parental respiratory illness (table 2). Children whose parents had a positive history had 72 to 155% higher illness and symptom rates than did children whose parents had a negative history. Because parental history could be either an intermediate or a confounding variable for the effects of gas cooking and sidestream cigarette smoke, analyses of these risk factors are presented both with and without adjustment for family illness history.

Individual values of *ln* FVC and *ln* FEV_1 were adjusted for sex and age by subtracting the sex-, age-, height-, and weight-specific predicted values from each observation (30). Consequently, mean residuals of FVC and FEV_1 (expressed in percent) were not significantly associated with either sex or age (table 3). Pulmonary function residuals were smaller at the first than at the second examination for both boys and girls. This was due primarily to poor performance of the spirometric maneuver at the first examination. Mean residuals differed significantly among the cities. The city-specific means are similar at the 2 examinations for 4 of the 6 cities. Topeka and St. Louis show significant increases between the first and second examinations. Thus, further analyses of the effects on pulmonary function level of exposure to gas cooking and parental smoking were adjusted for city-cohort.

Although adjusted mean residuals of FVC and FEV_1 increase with level of parental education (table 3), neither association is significant. Parental respiratory illness history is not significantly associated with either FVC or FEV_1.

Parental Smoking

When children were classified by maternal smoking status, children of nonsmokers had the lowest illness or symptom rate, children of current smokers the highest rate, and children of ex-smokers had an intermediate rate for all 8 illnesses and symptoms studied (table 4). The rates for the 3 exposure groups were significantly different ($p < 0.01$) in every instance. The same general pattern was observed when children were classified by paternal smoking status, but with occasional exceptions, and the differences between exposure groups were not uniformly significant. Thus maternal smoking status was a consistently stronger risk factor than paternal smoking status. When current maternal and paternal smoking status were considered simultaneously, children of 2 smoking parents were at highest risk for every outcome except bronchitis in the previous winter (table 4). Results of logistic regressions were consistent with an additive effect of the number of smoking parents on the risk of illness.

Illness and symptom rates had a strong linear relationship on the logistic scale with level of maternal smoking, measured as the reported current daily cigarette smoking by the child's mother (table 5). (Ex-smokers were excluded from this analysis.) The linear association was highly significant ($p < 0.001$) for every outcome except bronchitis for the last year ($p = 0.01$) and respiratory illness in the previous year at the first examination ($p = 0.09$). A nonlinear component for these relationships could not be identified for any illness or symptom. Linear relationships were also found when the analysis was restricted to children of housewives, and when the combined current daily cigarette smoking of the father and mother was used to estimate level of exposure. However, the comparisons with maternal smoking level produced the strongest associations.

A reported parental history of bronchitis, emphysema, or asthma was a highly significant independent risk factor for each of the illnesses and symptoms studied (table 6). Odds ratios for the 8 outcomes by parental history varied from 1.99 to 2.88. Adjustment for parental respiratory illness history reduced the estimated effects of maternal smoking on respiratory illnesses and symptoms, but the associations remained positive and in 5 of the 8 outcomes considered, statistically significant.

Adjustment for the educational attainment of the parents reduced only slightly the estimated effects of mater-

TABLE 3

MEAN RESIDUAL PULMONARY FUNCTION (%)* AT FIRST (n = 8,994) AND SECOND EXAMINATIONS (n = 7,145) BY SEX, AGE, CITY, PARENTAL EDUCATION, AND REPORTED PARENTAL ILLNESS HISTORY

	1st Examination		2nd Examination	
	FVC	FEV_1	FVC	FEV_1
Sex				
Boys	−0.35	−0.18	+1.21	+0.80
Girls	−0.24	−0.12	+1.01	+0.80
Age				
6	−0.38	+0.03		
7	−0.47	−0.27	+1.01	+0.77
8	−0.28	−0.28	+1.01	+0.93
9	+0.72	−0.06	+1.01	+0.57
10			+0.92	+0.89
City				
Portage	+2.70	+2.14	+2.87	+2.57
Topeka	−1.81	−1.73	+2.30	+1.54
Watertown	−1.94	−0.95	−2.00	−0.59
Kingston	+0.22	−0.92	+0.64	−0.40
St. Louis	−0.66	−0.34	+1.36	+0.90
Steubenville	+0.42	+0.81	+0.66	+0.23
Parent's Education				
<High school	−0.41	−0.54	−0.23	−0.44
High school	−0.13	−0.14	−0.13	−0.17
>High school	+0.38	+0.45	+0.39	+0.52
Parent's Illness				
No	+0.02	+0.24	+0.02	+0.13
Yes	+0.23	−0.27	+0.21	−0.23

Definitions of abbreviations: FVC = forced vital capacity; FEV_1 = forced expiratory volume in one second.
* Expressed as change from 100% in ratio of observed to expected value.

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TABLE 4

FREQUENCY (RATE PER 1,000) OF REPORTED ILLNESSES AND SYMPTOMS (AND STANDARD ERRORS) BY PARENTAL SMOKING AND STOVE TYPE, DIRECTLY STANDARDIZED FOR AGE, SEX, AND CITY

	1st Examination				2nd Examination				
	Number at 1st Examination	Doctor-Diagnosed Illness before age 2	History of Bronchitis	Respiratory Illness Last Year	Respiratory Illness Last Year	Bronchitis	Cough	Wheeze	Low Res; rato inde
Smoking Status									
Mother									
Never	4,044	193 (6)	137 (5)	124 (5)	130 (6)	74 (4)	78 (5)	99 (5)	205 (
Ex	1,485	205 (11)	152 (9)	131 (9)	147 (10)	78 (7)	93 (8)	114 (9)	239 (
Current	4,208	242 (7)	159 (6)	149 (5)	150 (6)	95 (5)	98 (5)	128 (6)	243 (
Unknown	372								
Father									
Never	1,832	185 (10)	135 (8)	129 (8)	127 (9)	79 (7)	76 (7)	104 (8)	202 (
Ex	1,784	204 (10)	160 (9)	123 (8)	138 (8)	89 (7)	79 (7)	106 (8)	222 (
Current	5,171	229 (6)	149 (5)	137 (5)	143 (5)	82 (4)	97 (5)	119 (5)	231 (
Unknown	1,319								
Current Parental									
Neither	2,726	173 (12)*	130 (10)*	123 (6)	129 (7)	76 (5)	77 (6)	99 (6)	206 (
Father Only	2,193	203 (8)	141 (7)	130 (7)	134 (8)	73 (6)	87 (6)	107 (7)	217 (
Mother Only	817	209 (17)	151 (15)	137 (12)	144 (13)	100 (11)	76 (10)	117 (12)	227 (
Both	2,792	235 (7)	160 (6)	143 (7)	148 (8)	90 (6)	106 (7)	131 (7)	240 (
Unknown	1,578								
Stove Type									
Gas	4,685	218 (8)	140 (7)	146 (7)	135 (8)	88 (7)	88 (6)	126 (9)	235 (
Electric	5,035	204 (7)	161 (6)	135 (6)	144 (8)	86 (5)	88 (5)	116 (6)	222 (
Unknown	386								

* Based on smoking history rather than on current smoking.

nal smoking on respiratory illness and symptoms; however, in all cases, a statistically significant positive relationship remained. In particular, for wheeze, which had the strongest association with parental education (table 2), the estimated odds ratio for exposure to maternal smoking of 1 pack per day relative to no exposure was 1.30 (95% confidence interval, 1.15 to 1.47), when adjusted for parental education, versus 1.34 (1.19 to 1.47) without adjustment. The χ^2 test for linear trend was 17.86 ($p < 0.0001$) after adjustment for parental education. A similar result was obtained using Green's index of socioeconomic status (32).

The FVC was significantly higher for children of mothers who were either current or ex-smokers, relative to children of nonsmokers, at the first examination ($p < 0.05$) (table 7). A nonsignificant association in the same direction was observed at the second examination. A similar pattern was observe based on the father's smoking. Children whose mothers were currer smokers had 0.6% lower mean FEV than children of nonsmokers at the firs examination ($p = 0.03$) and 0.9% lowe mean level at the second examinatio ($p < 0.001$). Children of ex-smokin mothers had the largest FEV_1 residual at both examinations. The difference between the ex-smoking and curren smoking groups were significant ($p < 0.05$), whereas those between the ex smoking and nonsmoking groups wer not. Children whose fathers were cur rent smokers had a reduction in FEV of 0.01% at the first examination (NS and 0.7% at the second ($p = 0.03$). relative to children of nonsmokers. Among current smokers, materna smoking was more strongly associated with reduced FEV_1 than was paternal smoking when the two exposures were considered jointly (table 7).

TABLE 5

RELATIVE ODDS OF RESPIRATORY ILLNESSES AND SYMPTOMS BY MOTHERS' REPORTED DAILY SMOKING, COMPARED WITH CHILDREN WHOSE MOTHERS REPORTED NEVER SMOKING

		Maternal Smoking Current Daily Smoking							Linear Trend	
	Number	0	1–5	6–15	16–25	26–35	36–45	46+	χ^2	p
Doctor-Diagnosed respiratory illness before age 2	7,273	1.00	1.04	1.09	1.42	1.48	1.58	2.69	41.88	0.0000
History of bronchitis	7,944	1.00	1.03	1.19	1.20	1.42	1.26	2.04	13.68	0.0002
Respiratory illness last year (1st exam)	7,507	1.00	1.58	.97	1.15	1.56	1.01	1.07	2.95	0.086
Respiratory illness last year (2nd exam)	6,613	1.00	1.06	1.07	1.15	1.42	1.64	1.26	13.13	0.0003
Bronchitis last year	6,613	1.00	1.74	1.24	1.25	1.06	1.63	1.58	6.34	0.012
Cough last year	6,594	1.00	1.01	1.30	1.11	1.46	2.12	1.24	14.52	0.0001
Wheeze last year	6,578	1.00	1.17	1.11	1.27	1.39	2.31	1.35	24.94	0.0000
Lower respiratory index	6,578	1.00	1.15	1.09	1.20	1.29	1.78	1.87	23.82	0.0000

Current maternal smoking level was significantly linearly associated with increased FVC ($p = 0.006$) only at the first examination. A highly significant negative association ($p < 0.001$) between maternal smoking level and FEV_1 was found at both examinations (figure 1). If a child's mother smoked 1 pack of cigarettes per day, the estimated reduction in the child's FEV_1 was 0.7 ± 0.2% at the first examina-

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TABLE 6

ODDS RATIOS FOR RESPIRATORY ILLNESSES AND SYMPTOMS BY REPORTED PRESENCE OF RESPIRATORY ILLNESS IN PARENTS AND MOTHERS' SMOKING 1 PACK/DAY, WITH AND WITHOUT ADJUSTMENT FOR PARENTAL RESPIRATORY ILLNESS HISTORY. ALL ANALYSES ARE CONTROLLED FOR AGE, SEX, AND CITY-COHORT

	Number	Parents' Illness Only	Mothers' Smoking Only	Mothers' Smoking Controlled for Parent's Illness
Doctor-diagnosed respiratory illness before age 2	6,676	2.05*	1.35*	1.28*
History of bronchitis	6,675	2.77*	1.16*	1.07
Respiratory illness last year (1st exam)	6,679	2.16*	1.25*	1.18*
Respiratory illness last year (2nd exam)	5,414	1.99*	1.15†	1.09
Bronchitis	5,416	2.88*	1.19†	1.08
Cough	5,401	2.11*	1.34*	1.26*
Wheeze	5,385	2.30*	1.31*	1.23*
Lower respiratory index	5,390	2.32*	1.23*	1.16‡

* $p < 0.001$.
† $p < 0.05$.
‡ $p < 0.01$.

tion and 0.8 ± 0.2% at the second examination. Adjustment for parental education did not change appreciably the estimated effect of smoking on FVC or FEV_1.

Because of the positive association between passive smoke exposure and respiratory illnesses and symptoms in these children, the regression analyses of FVC and FEV_1 were repeated, controlling for each of the illnesses and symptoms. There was no significant association between FVC or FEV_1 and any of the respiratory illnesses or symptoms in the previous year. The FEV_1 was significantly reduced for children with a reported history of bronchitis or respiratory illness before 2 yr of age, −1.5% at the first examination ($p < 0.001$) and −1.3% at the second examination ($p < 0.001$). The FVC was also reduced by −0.5 and −0.2%, but the differences were not significant. Controlling for such a history did not substantially change the estimated effect of maternal smoking. For example, the estimated reduction in FEV_1 associated with maternal smoking of 1 pack per day, controlling for history of respiratory illness, was 0.7 ± 0.2% at both examinations (table 7).

To investigate the possibility of differential effects of parental smoking on boys and girls, the analysis of each pulmonary function and respiratory illness outcome was repeated separately for boys and girls, using maternal smoking level as the risk factor. For the 8 respiratory illness and symptom outcomes, the estimated effect of maternal smoking was larger in boys in 5 instances and larger in girls in 3 instances (results not shown). The difference in the odds ratios was not statistically significant for any of the 8 outcomes. Similarly, the estimated reduction in FEV_1 associated with maternal cigarette smoking did not differ significantly for boys and girls.

TABLE 7

MEAN RESIDUAL PULMONARY FUNCTION LEVEL* (AND STANDARD ERROR) BY SMOKING STATUS AND TYPE OF COOKING STOVE, ADJUSTED FOR CITY-COHORT

	1st Examination		2nd Examination	
	FVC	FEV_1	FVC	FEV_1
Smoking Status	%	%	%	%
Mother				
Never	−0.40 (0.21)	+0.17 (0.19)	−0.14 (0.21)	+0.37 (0.19)
Ex	+0.55 (0.33)	+0.84 (0.31)	+0.26 (0.33)	+0.42 (0.31)
Current	+0.14 (0.19)	−0.48 (0.18)	+0.02 (0.21)	−0.53 (0.20)
Father				
Never	−0.45 (0.30)	−0.05 (0.29)	+0.24 (0.30)	+0.57 (0.29)
Ex	+0.41 (0.30)	+0.66 (0.28)	+0.03 (0.28)	+0.41 (0.27)
Current	+0.07 (0.18)	−0.06 (0.17)	−0.01 (0.19)	−0.13 (0.18)
Current parental				
Neither	−0.75 (0.37)	−0.17 (0.36)	+0.33 (0.38)	+0.83 (0.35)
Father only	+0.11 (0.27)	+0.61 (0.26)	−0.13 (0.28)	+0.18 (0.26)
Mother only	+0.38 (0.45)	−0.09 (0.43)	−0.40 (0.43)	−0.72 (0.44)
Both	+0.01 (0.25)	−0.65 (0.24)	+0.08 (0.26)	−0.41 (0.25)
Stove type				
Electric	+0.33 (0.18)	+0.36 (0.17)	+0.16 (0.18)	+0.14 (0.17)
Gas	−0.32 (0.19)	−0.33 (0.18)	−0.16 (0.19)	−0.14 (0.19)

For definitions of abbreviations, see table 3.
* Expressed as change from 100% in ratio of observed to expected value.

Gas Cooking

Directly standardized rates of reported illnesses and symptoms (table 4) failed to show a consistent pattern of increased risk for children from homes with gas stoves compared with children from homes with electric stoves. Logistic analyses (not shown) controlling for age, sex, city-cohort, and maternal smoking level gave estimated odds ratios for the effect of gas stoves ranging between 0.93 and 1.07 for bronchitis, cough, wheeze, lower respiratory index, and illness for the last year reported at either examination. None of these odds

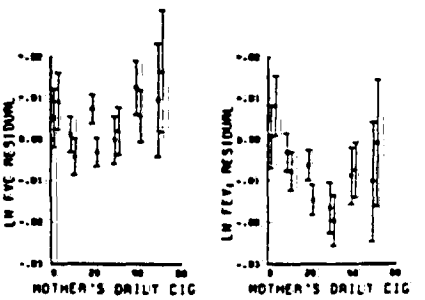

Fig. 1. Mean *ln* pulmonary function residuals (± 1 SD) by mothers' reported daily cigarette smoking, compared with children whose mothers have never smoked. Squares represent the first examination (n = 7,112) and triangles represent the second examination (n = 6,278).

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ratios was significantly different from 1. Only the odds ratios (OR) for history of bronchitis (OR = 0.86; 95% confidence interval, 0.74 to 1.00) and respiratory illness before the age of 2 (OR = 1.13; 95% confidence interval, 0.99 to 1.28) approached statistical significance.

Use of gas stoves was strongly associated with parental educational attainment. The percentage of homes using gas stoves was 65% for families in the group with lowest education, 46% in the middle group, and 33% in the highest. When the logistic analysis was repeated with adjustment for parental education, the estimated odds ratio for illness before 2 yr of age was 1.11, with a 95% confidence interval of 0.97 to 1.27 ($p = 0.14$).

Children from homes with gas stoves had lower pulmonary function levels than did children not exposed to gas stoves at both examinations. The deficits at the first examination were 0.6% ($p = 0.01$) for FVC and 0.7% ($p = 0.03$) for FEV_1. At the second examination, the mean reduction was 0.3% ($p = 0.17$) for FVC and 0.3% ($p = 0.26$) for FEV_1. All comparisons were controlled for city-cohort and maternal smoking level. After adjustment for parental education, the estimated deficits associated with exposure to gas stoves were reduced by 30% for both FVC and FEV_1 at the first examination and were no longer significant.

Discussion

These analyses show a consistent association between parental cigarette smoking and increased respiratory illness during childhood. Of the children in this sample, 43% had mothers who were current smokers (table 4), 59% had fathers who were current smokers, and 68% had at least one parent who was a current smoker. Thus, effects of sidestream cigarette smoke of the size observed in this study would represent a substantial public health burden.

Current maternal cigarette smoking was associated with a 20 to 35% increase in the risk of all respiratory illnesses and symptoms in the past year. A history of either parent smoking was associated with a similar increase in the reported prevalence of early childhood respiratory illness. Each of these respiratory health indexes is linearly related to the current amount of cigarette smoking by either both parents or the mother alone. In all of these analyses, the association between impaired health and passive smoke exposure was stronger with maternal than with paternal or total parental smoking. Children of exsmokers had respiratory illness and symptom frequencies that were typically between those of nonsmoking and currently smoking mothers. This was true for recent illness and symptom experience, as well as for early childhood illnesses. These findings are consistent, at least in part, with the hypothesis that exposure to cigarette smoke increases the risk for contemporaneous respiratory illness.

The stronger association with maternal rather than paternal smoking for these conditions is consistent with the independent findings of other investigators. Fergusson and coworkers (13) found respiratory illness in the first year of life to be highly associated with maternal smoking, and paternal smoking did not enter their model after controlling for maternal smoking. In their birth cohort of 1,265 children, the association between maternal cigarette smoking and respiratory illness was equivocal in the second year of life and no longer apparent during the third year. Weiss and associates (11) found persistent wheeze to be directly related to the number of smokers in the household among children 6 to 19 yr of age. Subsequent analyses of these data (36) confirmed that the association is strongly influenced by maternal smoking. Similar findings restricted to children 5 to 11 yr of age have been reported by Schenker and associates (37).

The somewhat stronger association of respiratory illness with maternal than with paternal smoking habits need not imply any special risk associated with maternal smoking. A more plausible interpretation is that the risk factor is exposure to sidestream cigarette smoke, and that children are more likely to be with their mothers than with their fathers at the times smoking occurs.

Although some investigators have not reported significant passive smoking relationships, their findings, given the size of the populations under investigation and methods used to adjust symptoms or disease rates, are consistent with our results. The total number of children younger than 10 yr of age available to Schilling and colleagues (19) was so small that a 20 to 35% increase in relative risk could not be detected. In contrast, Dodge (10) found a significant passive smoking effect t was reduced (as in our study) by adju ing for parental history of respirato disease. The resulting coefficients, though relatively unchanged in mag tude and direction, were no longer si nificant. However, in a small group sixth graders, who completed their ov questionnaire, the gradient acro smoking categories persisted and w significant.

Among the children participating the Six-Cities Study, there was a stror association between reported parent respiratory illness (emphysema, bro chitis, or asthma) and higher prev lence of symptoms and illness (tables and 6). This may be explained in pa by overreporting of the child's respira tory illnesses by smoking parents wh themselves have respiratory problems or equivalently by the underreportin of nonsmoking parents. Such reportin bias cannot be separated in these an alyses from real differences in preva lence caused by familial aggregation o higher susceptibility within families However, all the illnesses and symptoms still show increased prevalence associated with parental smoking after adjusting for parental illness (table 6). This suggests that passive environmental exposure to smoking is a cause of respiratory illness.

Changes in level of FEV_1, although relatively small, were linearly related to amount smoked (figure 1). For maternal smoking of 1 pack per day, FEV_1 is estimated to be lower by 0.6 to 0.8%, or 10 to 20 ml for a child with FEV_1 between 1.5 and 2.5 L. Tager and coworkers (17) found a comparable association when they used maximal midexpiratory flow (MMEF), although initially they were unable to demonstrate the effect with FEV_1. Subsequent studies of these same children demonstrated the passive smoking effect for both FEV_1 and MMEF (36). Similar effects were found in a study of 4,000 children in a rural area of western Pennsylvania (37). However, the Tucson group (38) was unable to demonstrate this effect after adjusting for the pulmonary function level of the parent. Because cigarette smoking is associated with level of pulmonary function, the adjustment for parental level of function may have resulted in overadjustment.

Because the association between FEV_1 level and parental cigarette smoking had not been found in a previous analysis of a subset of these data (28),

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a series of comparative analyses were performed in that subset and in the entire data set providing the basis for this report. Those analyses established that the lack of association in the earlier investigation was attributable in approximately equal measure to the use of parental rather than to maternal smoking as the exposure variable and to the use of a normative model for pulmonary function level derived from a small subset of the study participants living in 2 cities.

The FEV_1 levels were not reduced in children of ex-smokers. However, in our study, we did not determine when these parents became ex-smokers and therefore cannot assess whether these ex-smokers were in fact ever smokers during the lifetime of their children. We have similar difficulty in trying to assess whether the effect noted is due to current exposure, cumulative exposure, or exposure at some earlier point in time. Because most parents' smoking habits are not likely to have changed significantly over the course of their children's first 11 yr of life, all 3 effects, or any combination thereof, could be operative.

We note, as have others (Vedal S and associates. Risk factors for childhood respiratory disease: analysis of pulmonary function. Am Rev Respir Dis, submitted for publication), that FVC was highest in children from households with parents who smoke. Some studies suggest that young adult smokers may have larger FEV_1 and FVC than do nonsmokers; however, the reason generally offered is that young adults with a history of respiratory illness are relatively disinclined to smoke. This would appear to be an unlikely explanation for the differences seen in young adults and would not explain a corresponding response to sidestream cigarette smoke.

In assessing the strength of the evidence given above for an effect of sidestream cigarette smoke on respiratory health, it is important to remember that the various indexes are not independent. The correlations, or phi coefficients (34), between pairs of illnesses and symptoms reported here varied between 0.14 and 0.37. Correlations were highest for illness before 2 yr of age and history of bronchitis, history of bronchitis and bronchitis in the last year, and wheeze and cough. Although these correlations are highly significant and indicate strong associations between the various outcomes, they are not so large as to indicate that the different outcomes are redundant. The FVC and FEV_1 values are also highly correlated in young children. Because of the relationships among these outcomes, the many associations examined, and the large sample sizes, we have not emphasized individual p values in interpreting these data. Rather, we have looked for consistent patterns of association. The results for parental cigarette smoking fit that criterion.

These analyses provide less consistent evidence about the potential health significance of exposure to gas stoves. An estimated odds ratio for respiratory illness before 2 yr of age of 1.23 ($p < 0.01$) previously reported from this study (28, 29) has been reduced to 1.12 ($p = 0.07$) by the inclusion of additional children enrolled in the study but not available for the first analysis. A series of analyses comparing the 2 results established that this resulted primarily from the absence of an association between stove type and illness before 2 yr of age in the new cohorts rather than from small differences in models or statistical methods. No other respiratory illness or symptom was found to be significantly associated with stove type. Although respiratory illness before 2 yr of age may be a sensitive index of the effects of gas combustion products, such an association from these data should be interpreted cautiously because the analysis links exposure at 6 yr of age or older with illness before 2 yr of age.

These analyses confirm the earlier finding of approximately 0.6% lower FVC and FEV_1 levels at the first examination among children exposed to gas stoves. We also found a difference of 0.3% at the second examination. However, level of parental education is negatively associated with use of gas stoves and positively associated with pulmonary function level. Consequently, controlling for parental education reduces this association. This may represent confounding but may also represent overadjustment for a surrogate for gas stove use.

Controlling for city-cohort in these analyses substantially reduces, although it does not eliminate, the potential for bias caused by ethnic differences, examiner effects, equipment differences, and many other factors that influence indexes of respiratory health. However, the sensitivity of an analysis based on exposure categories, such as parental cigarette smoking, is limited by the weak relationship between these categories and individual exposure to gases or particulate matter. The documented variation in particulate and nitrogen dioxide concentrations among homes with equal numbers of smokers or the same type of stove (4–9) implies that the exposure variables used in these analyses are subject to substantial measurement errors. Although the effects of these errors are not completely understood (39), they are likely to bias the estimated measures of association toward the null value. Thus, better understanding of the health significance of these indoor pollutants may require epidemiologic studies including refined measurement of personal exposure.

Finally, the medical significance of these findings related to passive smoking remains undetermined. The illness and symptom effects may be transient, and the effects on pulmonary function levels appear to be small. However, to the degree that these small effects persist or accumulate in early adult life, they may represent an important predictor of risk, particularly among those who take up cigarette smoking. Long-term follow-up and comparisons between children from homes where others smoke will be required to resolve this potentially important public health question.

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